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6. AUTHOR(S)

T. A. Heath–Pastore, H. R. Everett

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Naval Command, Control and Ocean Surveillance Center (NCCOSC)
RDT&E Division
San Diego, CA 92152–5001

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The MDARS Interior Program successfully demonstrated the simultaneous control of two robots and four simulated robots operating in an interior warehouse environment. The command and control architecture is structured to accommodate up to thirt-two robots.

Initated in February 1993, the MDARS Exterior Program will provide commanders with an automated system to conduct random site patrols, barrier assessment, intruder detection and assessment, and inventory assessment in a semi-structured outdoor environment.

This paper briefly outlines the MDARS Interior and Exterior Programs and discusses the technical risks associated with the Exterior development approach.

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T. A. Heath–Pastore	(619) 553–3674	Code 531

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Coordinated Control of Interior and Exterior Autonomous Platforms

T. A. Heath-Pastore, H. R. Everett
Naval Command, Control, and Ocean Surveillance Center
RDT&E Division
271 Catalina Boulevard
San Diego, California 92152-7383

ABSTRACT

The Mobile Detection Assessment Response System (MDARS) Program is a joint Army-Navy effort to field interior and exterior autonomous platforms performing security and inventory assessment functions at DoD warehouses and storage sites. The program is managed by the Physical Security Equipment Management Office at Ft. Belvoir, VA.

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Initiated in February 1993, the MDARS Exterior Program will provide commanders with an automated system to conduct random site patrols, barrier assessment, intruder detection and assessment, and inventory assessment in a semi-structured outdoor environment.

This paper briefly outlines the MDARS Interior and Exterior Programs and discusses the technical risks associated with the Exterior development approach.

BACKGROUND

During Phase I of the MDARS Interior Program, a hybrid navigation scheme was developed under a Cooperative Research and Development Agreement between Cybermotion, Roanoke, VA, and the Naval Command, Control, and Ocean Surveillance Center (NCCOSC). This innovative concept combines Cybermotion's virtual path navigation approach with unrestricted path planning algorithms developed at NCCOSC for improved collision avoidance. The Phase II objective of the Interior Program is to field a supervised multiple-robot security and inventory

management system which basically runs itself until an unusual condition is encountered that requires human intervention.

The new-start MDARS Exterior Program seeks to provide an automated intrusion detection and inventory assessment capability for use in DoD outdoor storage areas. The development of the exterior system will build upon the extensive experience accumulated under the Interior Program.

SYSTEM OVERVIEW

The interior and exterior platforms will be guard-supervised from a single control console. NCCOSC initially developed the Multiple Robot Host Architecture (MRHA) (figure 1) to provide coordinated control of multiple autonomous vehicles (figure 2) operating in an indoor environment.

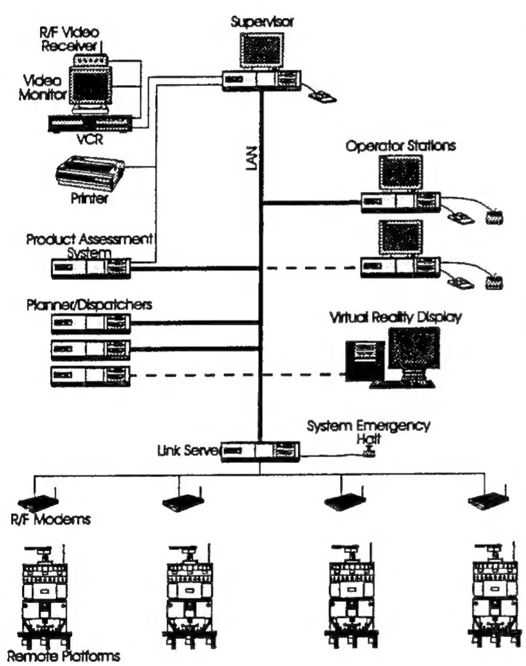

Figure 1. Multiple Robot Host Architecture.

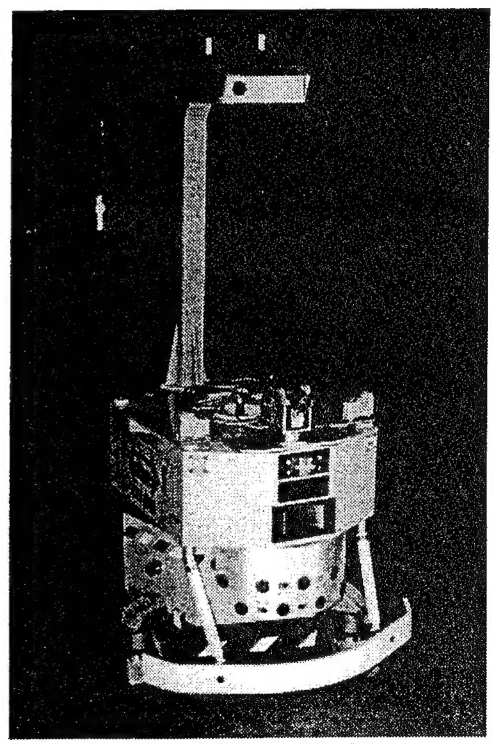

Figure 2. MDARS Interior Platform.

The interior robotic platforms utilize the Cybermotion K2A Navmaster base equipped with additional collision avoidance, intruder assessment, and product inventory subsystems. Exterior platforms are being developed by Robotic Systems Technology (RST), Westminster, MD.

TECHNICAL RISKS

The technological hurdles for MDARS Exterior are in many ways a further extrapolation of those issues facing the MDARS Interior Program, and similar to those encountered in the ARPA Unmanned Ground Vehicle Program. To put it into broad perspective, the MDARS Exterior Program poses a greater technical challenge

than the Interior Program due to the more unstructured nature of the operating environment. Conversely, the perceived problems are somewhat less severe than those associated with the Unmanned Ground Vehicle Program, in that envisioned MDARS Exterior operational scenarios are more structured than the unknowns of a battlefield environment.

For purposes of this discussion, these technical risks can be lumped under the following general areas: 1) basic platform, 2) autonomous navigation, 3) multiple platform command, control, and communication, and 4) mission-specific subsystems. Effective systems integration of all of the above into a cohesive and practical package poses additional risk to the successful fielding of MDARS Exterior.

Platform

The platform itself must be compatible with the environment in which it will operate, with a payload and power budget in keeping with the assigned mission. Relatively speaking, this is the most developed, lowest-risk area of concern. The bulk of the prior art in this arena, with a few notable exceptions, was in support of teleoperated systems which employed man-in-the-loop control strategies [1, 5]. Once an appropriate drive and power subsystem is selected, the task centers on remote-actuation of vehicle controls.

Autonomous Navigation

After the selected vehicle has been equipped with the appropriate actuator interfaces required for computerized control, it must be provided the sensory capability and intelligence to support autonomous navigation. Navigation, for this application, can be represented by four specific sub tasks:

- *Position Estimation.* The system must be able to ascertain the current position and orientation of the vehicle.

- *Path Planning.* The system must be able to plan an optimal path to the next desired location.

- *Navigational Re-referencing.* The vehicle must be able to periodically reset its navigational parameters (x, y, and heading) in the normal execution of path segments, so as to null out any accumulated dead reckoning errors.

- *Collision Avoidance.* The vehicle must be able to traverse the path segments without running into obstructions.

Bits and pieces of the technology needed to surmount these problems have been successfully demonstrated, but tying it all together into a *navigational scheme* for an exterior setting remains an elusive goal.

The MDARS Interior Program hybrid navigation scheme [4] holds significant promise for adaptation to the needs of an exterior robotic security system. For compatibility with the existing interior host console, an exterior parallel to the Cybermotion virtual path concept [3] must be developed and implemented on the remote platforms.

Command, Control, and Communications

After multiple platforms have been outfitted to support autonomous navigation, they can be employed in a coordinated fashion to attain a more robust and effective security system than can be realized with a collection of independent platforms. Coordinated control supports communication and information sharing between platforms and provides the human operator with more reliable information (fewer false events) fused from several platform sources. In addition, coordinated control is required to ensure full area coverage, non-interfering operation, and unpredictable routing.

Related development efforts to date have focused on demonstrating the feasibility of a single robotic platform operating under the high-level control of a remote host computer. It is impractical to consider a multiple-platform security system with such a one-to-one platform-host correspondence supervised by a single human operator. It is also impractical to employ several human operators in a multiple platform system. Both of these options result in higher acquisition and operating costs for both operator personnel and console hardware.

The solution to the problem lies in developing a high-level, multiple-platform host console. Such a control architecture should be designed to delegate command and control resources as required by exceptional conditions encountered by remote platforms on patrol. This approach, wherein a single guard supervises multiple platforms from an integrated console, eliminates the need for dedicated host hardware for each platform. Many of these command and control issues have been uncovered and resolved by development efforts for the Interior Program [2]. MDARS Exterior will capitalize on this work and adapt as required for exterior application.

The specific technical risks involved with implementing coordinated control of multiple platforms include the following:

- *Command and Control.* Coordinated control of multiple platforms must be addressed in such a way as to minimize hardware requirements and to reduce the burden of oversight imposed upon the guard.

- *Communications.* Simultaneous video, audio, and data communications for multiple platforms pose significant problems with regard to available bandwidth, frequency allocations, and mutual interference with other subsystems.

Application-Specific Risks

The ultimate objective of a robotic system is of course to perform some useful function in place of its human counterpart, with appropriate cost savings and improved capability. Demonstrated success in this regard is a prerequisite to the eventual fielding of prototype systems. Any technological issues that hinder the practical realization of this objective naturally represent significant risks to the program. In the MDARS Exterior Program, the application-specific risks can be broken down into two sub-categories addressing the currently envisioned security and inventory assessment functions of the platform.

For the security function, which translates into intrusion detection and assessment, the technical risks are as follows:

- *Intrusion Detection.* An exterior intrusion detection suite with the required range and field-of-view (FOV) is not felt to be near-term state-of-the-art and will require specialized development. The majority of prior art is concerned with highly-structured indoor scenarios.

- *High Security Locks.* Specialized hardware capable of monitoring and reporting the state of high security locks must be developed.

- *Integration with Fixed Security Sensors.* The outputs of any fixed sensors in the area of operation must be filtered to compensate for the motion of the MDARS platform, then graphically displayed in an integrated fashion.

- *Motion Detection on the Move.* A motion detection capability that functions while the platform itself is moving is a requirement for Phase II of the program. The only near-term solution to this problem is seen in vision-based systems, which have limited FOV, are expensive to realize, and draw significant power.

For the inventory assessment function, the technical risks are identical to those facing the MDARS Interior Program:

- *Inventory Tag Reader Hardware.* RF tag interrogators will be utilized to communicate with transponder tags attached to high-value or sensitive items to be monitored. The cost of the inventory tags must be realistic in comparison to the inventory being monitored. Effective read update rates, tag densities, and positional resolution of the hardware must be characterized, and an optimal solution achieved.

- *Inventory Database Development.* The MDARS inventory database must be compatible with existing automated inventory management systems in use.

SUMMARY

Technical development on the MDARS Exterior Program is underway with the first hardware demonstration scheduled for early 1995. NCCOSC is responsible for development of the multiple-robot control console. Mission-specific modules to support inventory data collection and high security lock interrogation are being developed by the Army Armament Research Development and Engineering Center (ARDEC), Picatinny Arsenal, NJ.

A Broad Agency Announcement (BAA) contract was awarded to RST for technical development of the autonomous platform, navigation scheme, communication link, and intrusion detection system. The BAA approach minimizes technical risk for the MDARS Exterior Program by funding the early development of identified technology base deficiencies, while allowing the government time to more fully prepare the data package needed for an eventual competitive procurement. In parallel, the government becomes more knowledgeable of related work, which minimizes duplication of effort, and facilitates more effective technical oversight of any subsequent development contracts. Ongoing efforts under the BAA in the meantime can be refocused to reflect the benefit of this real-time feedback, resulting in more effective utilization of BAA funds. The longer term impact of this approach is reduced time and cost in follow-on production.

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